Comparative Study for Asymmetrical Building with and without Bracing using SAP-2000

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Abstract : The formation of cracks, which can result in structural damage, can be greatly influenced by excessive lateral drift. As an outcome of this damage, the structure's strength is decreased & its actual strength is lessened. Larger & taller buildings, such as high-rise ones & bridges, tend to display more lateral drift. Boosting the stiffness & stability of the structure through structural bracing is a common method of controlling lateral drift. The impacts of several forms of structural bracing on building performance are discussed in this article. The historical backdrop of structural bracing is explored, along with the distinctions between different types of bracing in terms of their suitability for various building types & loading scenarios, mechanisms, technical details, benefits & downsides & their overall effects on structural behavior & performance. Because it results in safer, more sustainable & cost-effective buildings that will require less maintenance over their lifespan, adequate & efficient structural bracing is essential for every high-rise structure.

I. INTRODUCTION

Compared to static loads, dynamic ones can dramatically affect the reaction of a structure. Hence, the structure's characteristics—namely lateral rigidity & strength are essential for maximizing structural performance in facing the dynamic forces like as typhoons, earthquakes, blasts, & others. The stiffness of the building has a big impact on the P-delta effect experienced. Dynamic loading, especially that applied laterally, which may transmit a great deal of energy into the structure, is exemplified by base shear generated from earthquake ground motion. One must disperse some of the energy created by dynamic loads to avoid structural failure, therefore lowering too great lateral displacement. One of the best methods to fight lateral movement is structural bracing, which especially increases lateral stiffness & general stability tall & multi-story structures. This increases the capacity of the building to resist the lateral stresses & helps in lowering the internal stress by means of a suitable bracing system. Because of this, structural bracing has become rather common option all over the world for financial reasons. According to conventional method, three main factors control to the stiffness of a structure. Firstly, easier internal force routes provide a much stiffer structure. Secondly, when a building's load distribution is consistent, its stiffness is boosted. Thirdly, less internal forces cause an augmentation in structural stiffness. Combining braces accounting above three concepts would let one to create a stronger & affordable structure.

In construction, bracing involves the inclusion of structural elements into a building or a framework to boost its firmness & capability to undergo lateral forces, such as those engendered by earthquake or wind. These elements classically constructed from steel or wood & assist in channeling forces down to the base, thus avoiding the structure from bending or failing under such pressures. A braced frame supports a structural system to withstand wind & earthquake stresses. When resisting tension, the bracing is diagonal crosses. One diagonal bears all the strain, while the other is inactive based on the wind. One configuration is cross bracing.

II. PURPOSE OF BRACING

2.1. **Enhance Stability**: It boosts the structure's stiffness & steadiness; it renders more resistant to sway, buckle & any other kinds of deflections. **2.2**. **Resist Lateral Loads**: It plays a critical role in disturbing the lateral forces including wind–pressure, seismic–activities, & the weight of any machinery. **2.3**. **Prevent Collapse**: By establishing a sturdy & dependable ‘framework’ it helps in contributing to prevent the structural failure, thus ensuring the protection of inhabitants & preserving the integrity of the building. **2.4**. **Distribute Loads**: It facilitates even distribution of the loads throughout the structure to ease the stress concentrations & potential failure points.

III. TYPES OF BRACING

3.1 Diagonal Bracing: This is a common type & involves the adding up of ‘diagonal’ elements say rods or cables or may be angles to create a stable & stiff configuration, akin to K-bracing or X-bracing
3.2 Shear Walls: These are strong walls which are usually made of concrete & are designed to withstand lateral–forces due to their ‘shear strength’.
3.3 Core Walls: These provide a strong structure with significant lateral stability & encase the building's core, which houses either elevator or stairway or both.
3.4 Horizontal Bracing: It helps in transferring the horizontal forces to vertical–bracing systems by installing them at each floor level.
Active Bracing: These employ sensors & actuators to dynamically adjust the bracing in response to seismic events.

IV. BENIFITS OF BRACINGS

4.1. Enhanced Safety: The integration of bracing significantly boosts the structural safety, particularly in areas that are prone to earthquakes or high winds. It serves several essential functions in buildings & bridges, both new & retrofitted like.

4.2. Augmented Load Capacity: This supports a structure's flexibility by letting it to endure larger loads & forces.

4.3. Decreased Maintenance: Throughout the lifespan of the building if a bracing is effectively designed it can help to reduce the necessity for maintenance & repairs.

4.4. Lateral Stability: It produces triangulated systems that stop too much sway & out-of-plane motion brought on by seismic or wind events.

4.5. Force Transfer: Utilizing bracing channels to effectively steer lateral forces away from important columns & beams toward the building's foundations.

- Limiting out-of-plane buckling helps structural parts to bear greater loads, therefore allowing for more economical member sizing.
- Well-designed bracing systems can absorb & disperse energy throughout seismic events, sustaining large plastic deformations.
- Redundancy helps to protect against progressive failure should unanticipated loads or local failures occur.
- Steel braces are often employed to enhance outdated buildings lacking sufficient lateral resistance, especially in earthquake modifications of reinforced concrete frames.

These benefits make bracing absolutely necessary to ensure occupant safety, maintain code compliance, & guard building investments.

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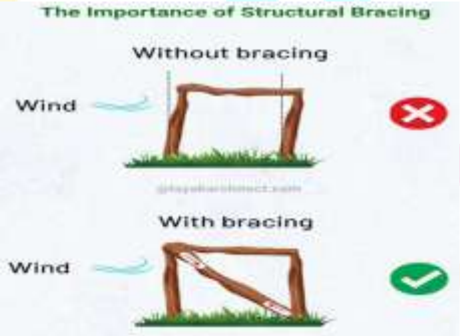


Figure 4.1.1. Bracing importance

V. SEISMIC ANALYSIS

Seismic analysis is about understanding how structures & infrastructure respond to earthquake loads. Engineers use different methods to analyze seismic loads based on the complexity of the structure, the seismic zone, & even what stage of design they are in. Here are the main types:

5.1 Methods of Seismic Structural Analysis

5.1.1. Equivalent Static Analysis:

•The equivalent static analysis approach uses simplified methods to response of a structure to earthquake ground motions by applying static force.

•It is suitable for wow-rise, regular buildings in low to moderate seismic zones.

•The limitation is, it doesn't respond to dynamic behavior & ignores any response from vibration modes higher than the fundamental mode.

5.1.2. Response Spectrum Analysis:

•It’s is a tool that applies response spectrum (mapping of the response based on a structural concepts) to evaluate how a structure reacts to various frequencies of ground motion.

•It is good for meduim & complex structures, such as bridges & industrial structures.

•The main advantage is it captures dynamic effects without conducting full time history analysis.

5.1.3. Linear Dynamic Analysi

•This approach solves the equations of motion derived from the structural properties, mass (inertia), stiffness (restraint), & damping (energy dissipation).

•Its is well applicable for moderate complexity structures that can demonstrate linear behaviour.

•The advantage of this one is more reliable when comparing static methods to dynamic methods, however can only be used with linear behaviors is assumed in structural material.

5.1.4. Non-linear Static Analysis (Pushover Analysis)

•This analysis applies incremental static loads to a structure while visually demonstrating how the structure continues to yield & deform as load is applied.

•This is good for performance based analysis when modelling performance during a significant seismic event.

•The main advantage is non-dimensional actions provide details on failure mechanisms & plastic hinge formation

5.1.5. Non-linear Dynamic Analysis

- This is the most advanced in terms of accuracy - simulating full earthquake time-history with nonlinear material behavior.
- It can be used for critical infrastructure & high-risk locations.
- The main advantage of this is, it gives unmatched accurate results, but can be computationally intensive.

5.2. WIND LOAD ANALYSIS

Wind load analysis evaluates the imposed forces by wind on a structure in order that stability, safety & serviceability are not compromised under various wind conditions. It is another fundamental part of structural engineering, especially for buildings, towers, bridges, & any other asymmetric structures exposed to atmospheric forces. Below is a full breakdown about wind load analysis & how designers tackle wind loads

These forces can cause: Lateral displacement (or sway), Uplift on roofs, Pressure differentials across surfaces, Fatigue or failure of structural components, Important parameters that influence wind load analysis:

5.2.1 Wind Loads Types

- Static Wind Loads
- Presumes steady wind pressure.
- For simple buildings.
- Dynamic Wind Loads

5.2.2 Specification / Codes of Practice

Most countries have established codes of practice that dictate methodology for wind load analysis. For example, in India is IS–875 Part–3, & in the U·S·A·, ASCE–7:-16, etc. These include details:

- Maps with Wind speed
- Formula to calculate wind loads
- Safety factors
- Risk categories

5.2.3 Impacts on Structures

- Tall buildings: sway & vortex shedding
- Warehouses: Large surface area increases drag force
- Rooftops: Vulnerable to uplift & suction
- Glass facades: Sensitive to pressure changes

VI. AS PER IS· CODE

Wind load analysis as per IS· 875 Part· 3 involves calculating the wind loads on structures to ensure they can withstand various wind conditions. Here's a breakdown of the key aspects:

6.1 Key Parameters

6.1.1 Basic Wind Speed [Vb]: Obtained from wind speed maps, typically ranging from 33 MPs to over 50 MPs across different zones in India.

6.1.2 Design Wind Speed [Vz]: Calculated using Vz □ Vb * κ1 * κ2 * κ3 κ4, where κ1, κ2, κ3, and κ4 are modifying factors.

- κ1 [Probability Factor]: Accounts for the structure's importance and risk coefficient.
- κ2 [Terrain, Height and Structure Size Factor]: Depends on terrain category [I to IV] and structure height.
- κ3 [Topography Factor]: Considers effects of hills, ridges, and escarpments.
- κ4 [Cyclone Factor]: Applied in cyclone-prone areas.

6.2 Design Wind Pressure [Pz]

6.2.1. Calculation: Pz ⇔ 0.6 X Vz^2 [in N/m^2].

6.2.2. Minimum Design Wind Pressure: Not less than 0.7 X Pz

6.3 Wind Load Calculation

6.3.1. Wind Force [F]: F ⇔ [Cpe - Cpi] X A X Pd, where Cpe is external pressure coefficient, Cpi is internal pressure coefficient, A is surface area, and Pd is design wind pressure.

6.3.2. Pressure Coefficients: External [Cpe] and internal [Cpi] pressure coefficients vary based on structure geometry and wind direction.

6.4 Terrain Categories

Category 1: Exposed open terrain with few obstructions.
Category 2: Open terrain with scattered obstructions.
Category 3: Terrain with numerous closely spaced obstructions.
Category 4: Dense urban areas or forests.

6.5 Important Considerations

6.5.1. Wind Directionality Factor [Kd]: Typically 1.0 for local pressure coefficients.
6.5.2. Area Averaging Factor [Ka]: Varies based on component area.
6.5.3. Combination Factor [Kc]: Usually 0.9 for simultaneous wall and roof pressures.

VII. OBJECTIVES

7.1. Developing two models one without and second one with bracings using SAP

7.2. Analyzing the first model without bracing and checking if various analysis parameters are within the limit or not.
7.3. Generating second model and assigning X bracing at the corners of all the four faces of the model and performing the analysis.
7.4. Then comparing the results for both models and examining the effect of provision of bracing system to understand the efficiency of this bracing system**.**

VIII. RESEARCH METHODOLOGY

8.1 Project Data

For the purpose of this project we have considered a residential building 8 flats at each level. It is assumed to be provided with parking at ground level and from 1st floor till 14th floor we have a typical floor as shown in coming pages, 15th floor will be terrace. Hence basically this model will be a G plus 15 floor building.
We will develop two models using SAP.
Model 1 without bracing
Model 2 with X bracing

8.2 The Bracing analysis Procedure,

- Generate a structural model for the select plan and assign the structural geometry for it.
- Assign various member properties as per the requirement.
- Assign various loads that includes superimposed dead, live and earthquake loads as per code
- For the second model select and assign an appropriate bracing (X, V, K, chevron, and Eccentric) type by keeping architectural constraints & intended performance. Here we will go with X type at corners.
- Perform analysis
- Check if the drift has reduced and within the limits when compared the first model. Review the system to confirm that all the lateral deflection limits (drift) are satisfied & that serviceability in considering wind & minor seismic actions are within the allowable limits.
- Review & Iteration: Reiterate member sizes & arrangement as appropriate & confirm adequacy through global & local analysis.

8.3 Material & Load details

8.3.1 Materials

•Concrete Grade: M40, Steel Grade: Fe500, Seismic Zone: III

Loads (kN/sqm)

•Floor Finish: 1.0, Imposed Load:2.0/3.0, Imposed Load:1.50 (at Roof)

8.3.2 Wall Loads

8.3.2.1: 150 mm thick wall load:

Width of wall X (floor to floor height – beam depth) X density of block
0.15 thick x (3.0 – 0.35) X 17.65 = 7.02 kN per m(A)
Plaster thick on both sides X (floor to floor height – beam depth) X density of mortar
(0.02+0.015) X (3.0 – 0.35) X 20.40 = 1.89 kN per m (B)
(A)+ (B) = 7.02 + 1.89 = 8.91 = 8.90 kN per m (say)

8.3.2.2: Parapet wall load

Width of wall X height X density of block
0.15 thk x 0.9 X 17.65 = 2.38 kN per m(C)
Plaster thk on both sides X height X density of mortar
(0.02+0.02) X 0.9 X 20.40 = 0.73 kN per m (D)
(C) + (D) = 2.38 + 0.73 = 3.11 = 3.10 kN per m (say)

8.4 Model Details:

1. Floor to floor height:3.0m, 2. Column dimension:300x300mm, 3. Beam dimension:200x300mm, 4. Slab thickness:150mm

8.5 Seismic Parameters:

1. Seismic zones :V, 2. Soil type: type-II, 3. R(Response Reduction Factor): 3, 4. I(Importance Factor):1

8.6 MODELING STEPS

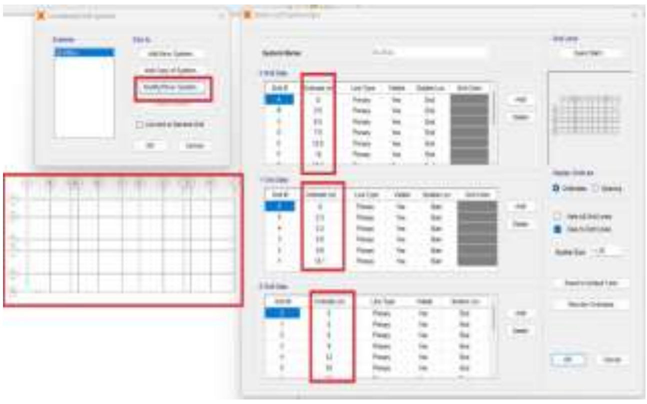


Figure 8.6.1: Adding grids & floors

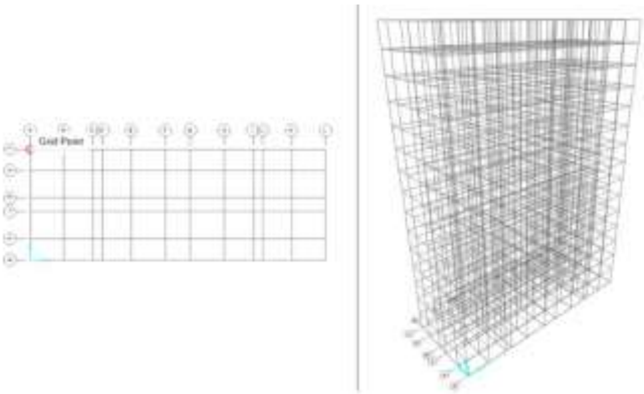


Figure 8.6.2: Grids in X Y & Z

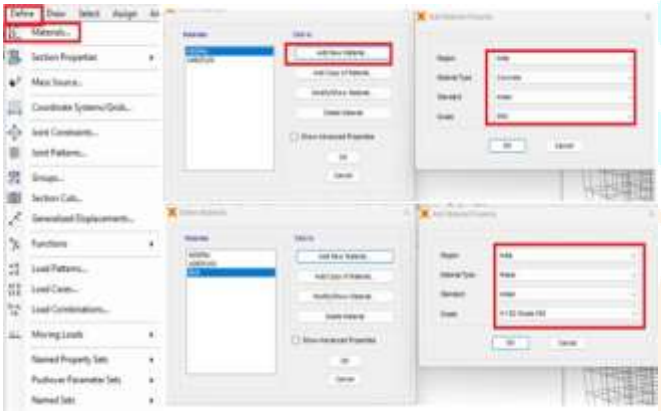


Figure 8.6.3: Defining materials

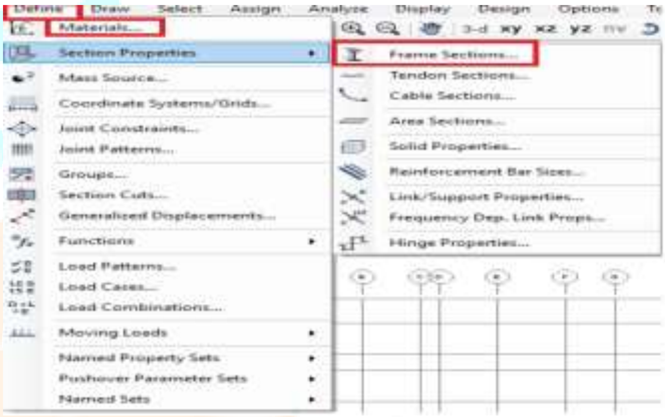


Figure 8.6.4: Defining sections

Figure 8.6.5: Defining columns

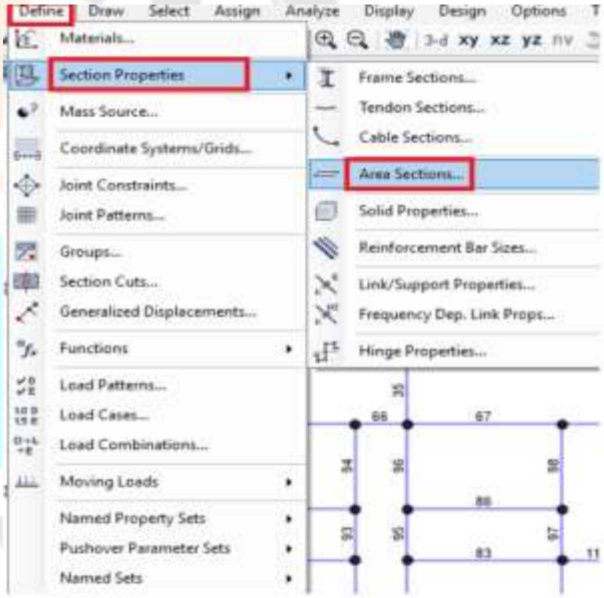
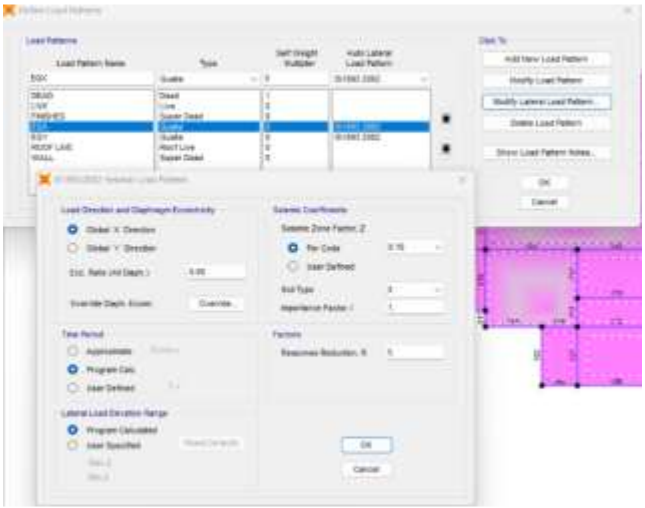
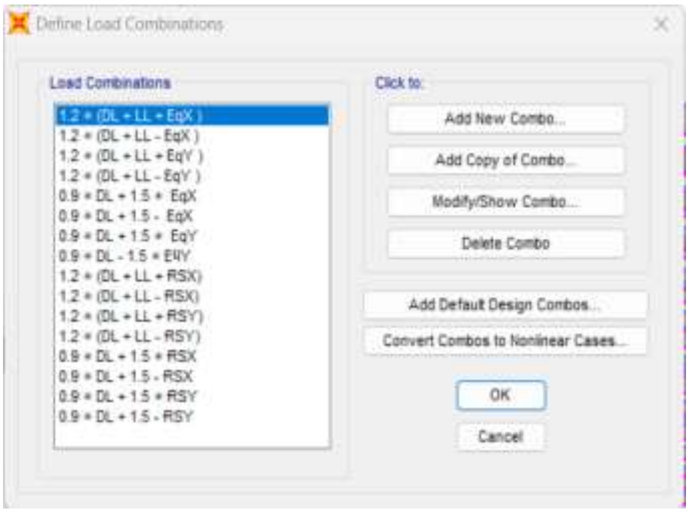


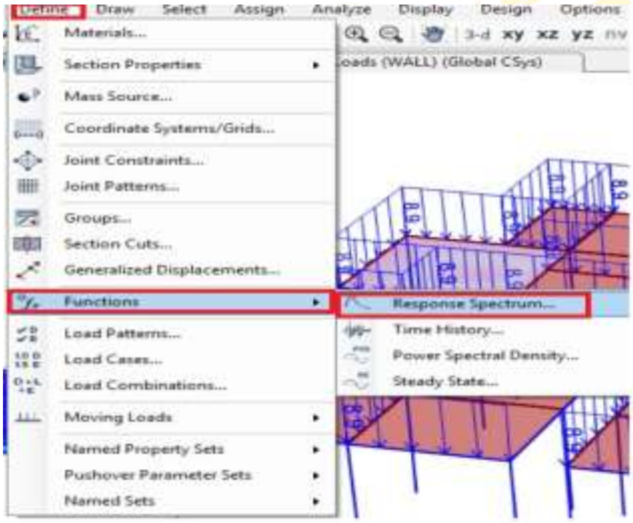
Figure 8.6.6: Adding slabs





1.2 * (DL + LL + EqX)
1.2 * (DL + LL - EqX)
1.2 * (DL + LL + EqY)
1.2 * (DL + LL - EqY)
0.9 * DL + 1.5 * EqX
0.9 * DL + 1.5 - EqX
0.9 * DL + 1.5 * EqY
0.9 * DL - 1.5 * EqY
1.2 * (DL + LL + RSX)
1.2 * (DL + LL - RSX)
1.2 * (DL + LL + RSY)
1.2 * (DL + LL - RSY)
0.9 * DL + 1.5 * RSX
0.9 * DL + 1.5 - RSX
0.9 * DL + 1.5 * RSY
0.9 * DL + 1.5 - RSY

Figure 8.6.7: Defining Loads **Figure 8.6.8: Defining Load combination**



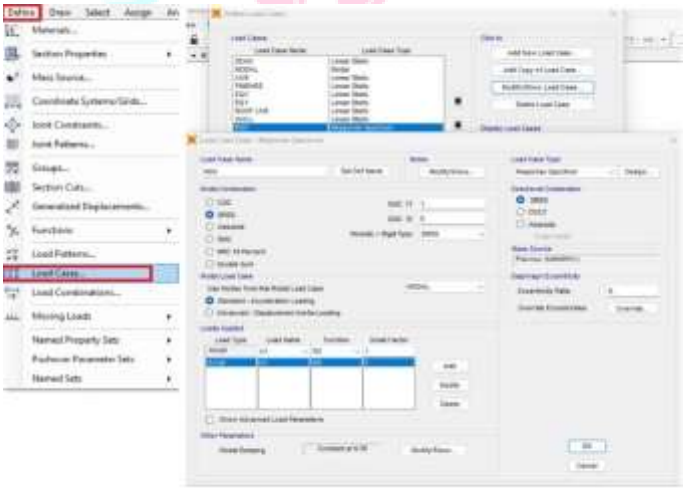


Figure 8.6.9: Defining Response Spectrum function **Figure 8.6.10: Adding Response Spectraum**

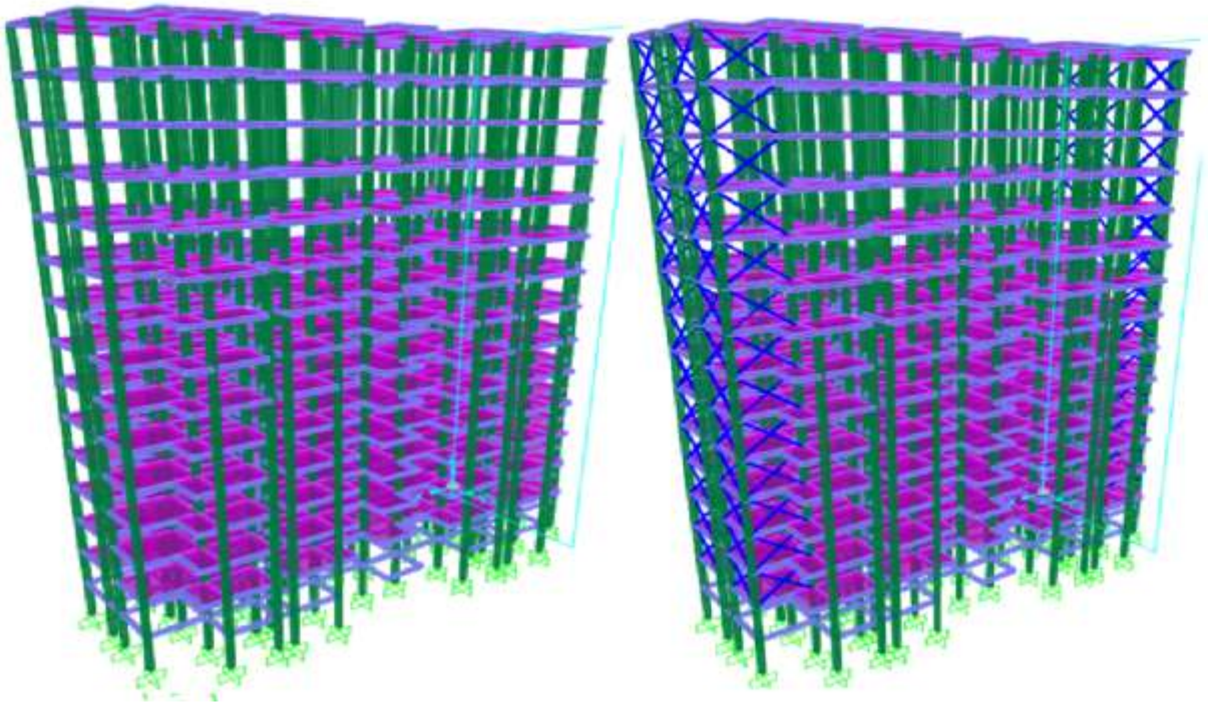


Figure 8.6.11: Iso view with and without bracings

IX. RESULTS AND DISCUSSION

Deflection in X & Y direction

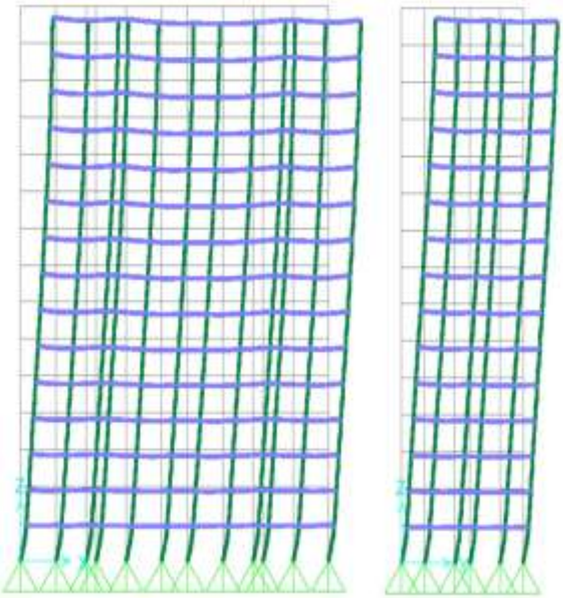


Figure 9.0.1: Without bracing

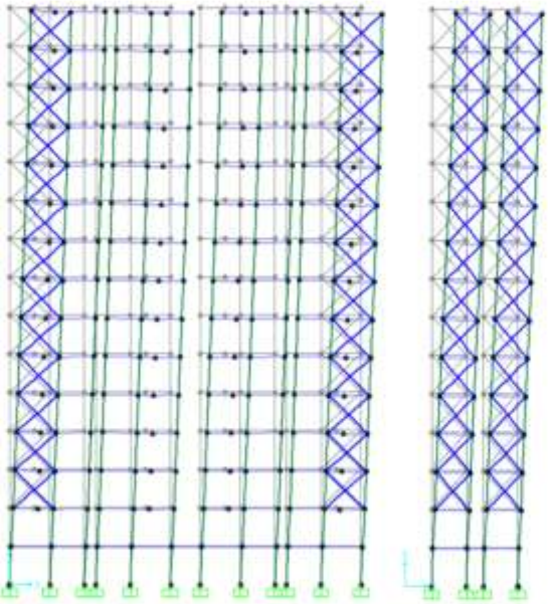


Figure 9.0.2: With bracing

9.1 Story Displacement:

STORY DISPLACEMENT, (mm) ® X		
1.2*(DL+LL+RSX)		
Story	Without Bracing	With Bracing
15	58.52	52.19
14	57.24	50.39
13	55.43	48.23
12	53.08	45.74
11	50.24	42.97
10	46.97	39.95
9	43.30	36.72
8	39.27	33.30
7	34.92	29.75
6	32.69	26.09
5	30.27	22.37
4	25.34	18.63
3	20.17	14.93
2	14.78	10.98
1	9.22	4.56
0	3.61	0.00

Table 9.1.1: Story displacement along X

STORY DISPLACEMENT, (mm) ® Y		
1.2*(DL+LL+RSY)		
Story	Without Bracing	With Bracing
15	86.92	53.38
14	84.35	50.98
13	81.04	48.25
12	77.03	45.26
11	72.41	42.03
10	67.25	38.59
9	61.63	34.99
8	55.58	31.26
7	49.16	27.44
6	42.41	23.58
5	35.37	19.72
4	28.05	15.92
3	20.50	12.26
2	12.76	8.58
1	4.84	3.35
0	0.00	0.00

Table 9.1.2: Story displacement along Y

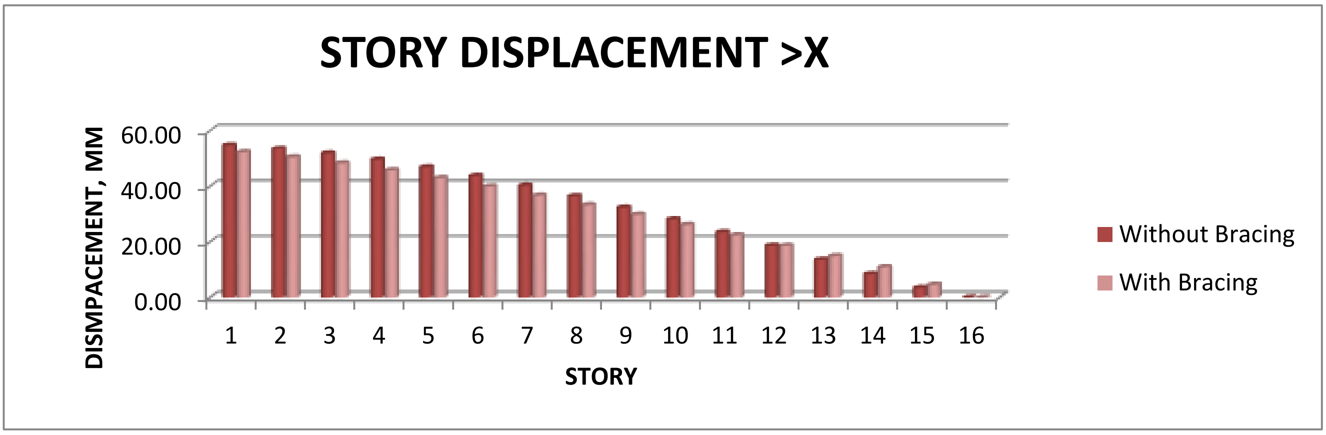


Chart 9.1.1: Story displacement along X

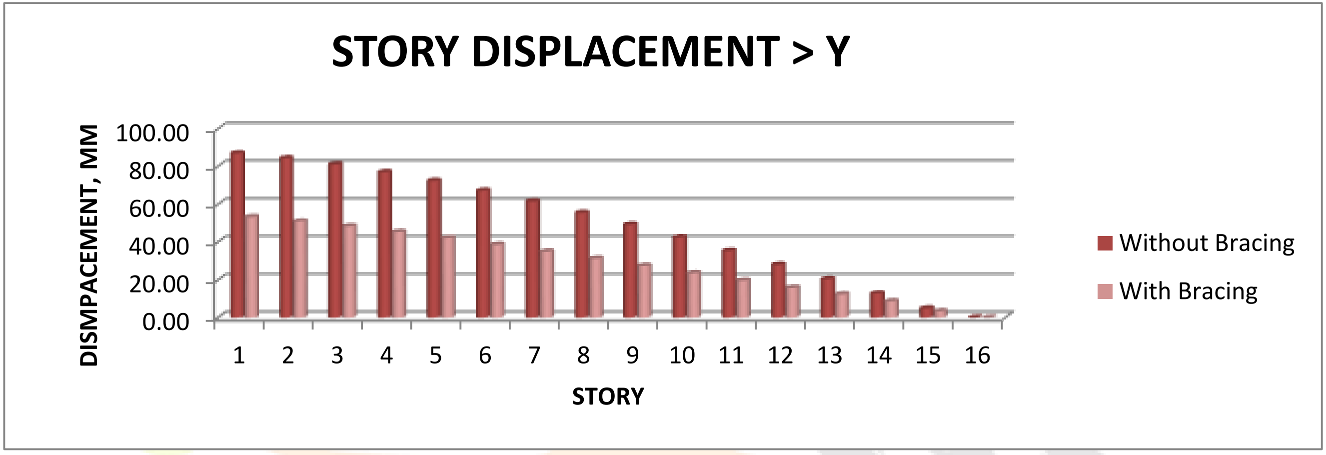


Chart 9.1.2: Story displacement along Y

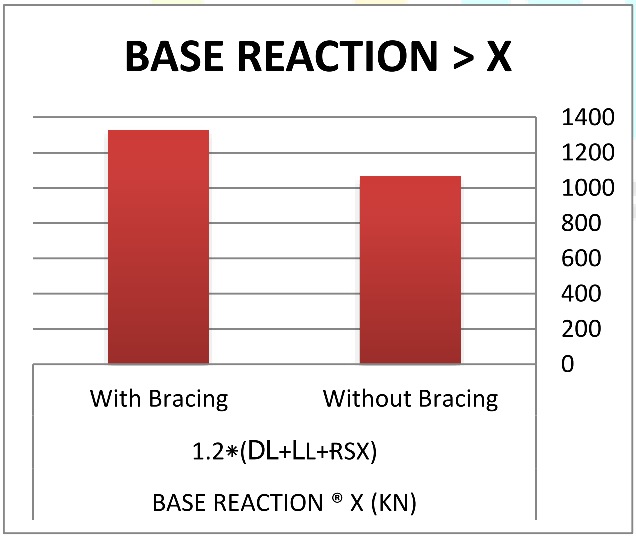
9.2 Base Reaction:

BASE REACTION → X (KN)	
1.2∗(DL+LL+RSX)	
Without Bracing	**With Bracing**
1067.34	1327.209

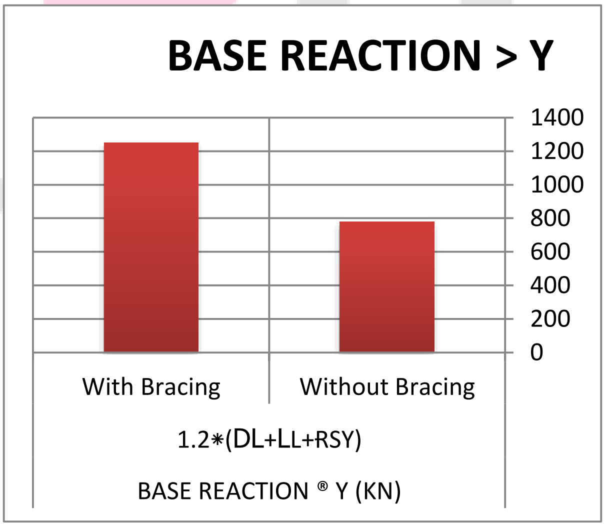
Table 9.2.1: Base Reaction along X

BASE REACTION → Y (KN)	
1.2∗(DL+LL+RSY)	
Without Bracing	**With Bracing**
777.354	1251.836

Table9.2.2: Base Reaction along Y



Graph 9.2.1: Story displacement along X



Graph 9.2.2: Story displacement along Y

X. CONCLUSION

The performance of two dissimilar structural systems one bare frame and another braced frame were investigated using the response spectrum analysis. And the outcome has been put forward as the essence of this work in point wise manner:

10.1. If we check the base reaction for the first model it is 1067.34 kN and 777.354 kN in X and Y respectively. For the second model corresponding values are 1327.209kN and 1251.836 kN. In both directions these have gone up for the second model. This increase in base reaction is due to addition of self weight of the bracing members.

10.2. When we observe the story displacement in X, for both the models, we find that for the first model it is 54.77mm (maximum) at the top and 3.42 mm (minimum) at the bottom. For the second model these values are 52.19 mm and 4.56 mm. So by comparing both these values, we can say there is not much contribution of introduction of bracing in X direction. Hence, we can still avoid these bracing in X direction. Of course in the first model the maximum allowable displacement is 180 mm which is obtained from formula H*0.004 of IS 1893 – 2002.

10.3. Similarly in Y direction, for the first model the story displacement is 86.92 mm (maximum) at the top and 4.84 mm (minimum) at the bottom. For the second model these values are 53.38mm and 3.35 mm. There is a difference of 33.55 mm. This is a big difference. Hence, addition of bracings in Y direction has brought down the displacement noticeably. However, in this direction also the displacement is within the limit. But from occupant's point of view lesser deflection means more safety.

10.4. When we compare the story drift introduction of bracings in both directions made to models behave uniformly from bottom floor to top floor. This is evident from the graph & charts. The values are almost between the values 3 & 4 for the second model. But for the first one this is ranging between 1 & 5.

10.5. Even in modal period, the period has come down but marginally. We don't see much difference here because in both the models the maximum displacement is closer and much within the applicable limits.

10.6. Both the models were similar from geometrical point of view also from member sizes point of view. After applying various loads, support conditions, etc, design of beams & columns was performed for factored dead and live load combinations. It was found that the selected sections were enough to take the loads coming over them. However, in some columns the % of steel is >4 and < 6. These can be increase to 350X 350 to bring down the steel < 4%.

10.7. Hence, we can say that the first model is safe as the displacement is within the limits in X & Y. At the same time second one is further safe from the occupant's point of view as the displacement is brought down further in Y direction

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